Deprocessing and SEM Evaluation of AlGaN /GaN HEMTs

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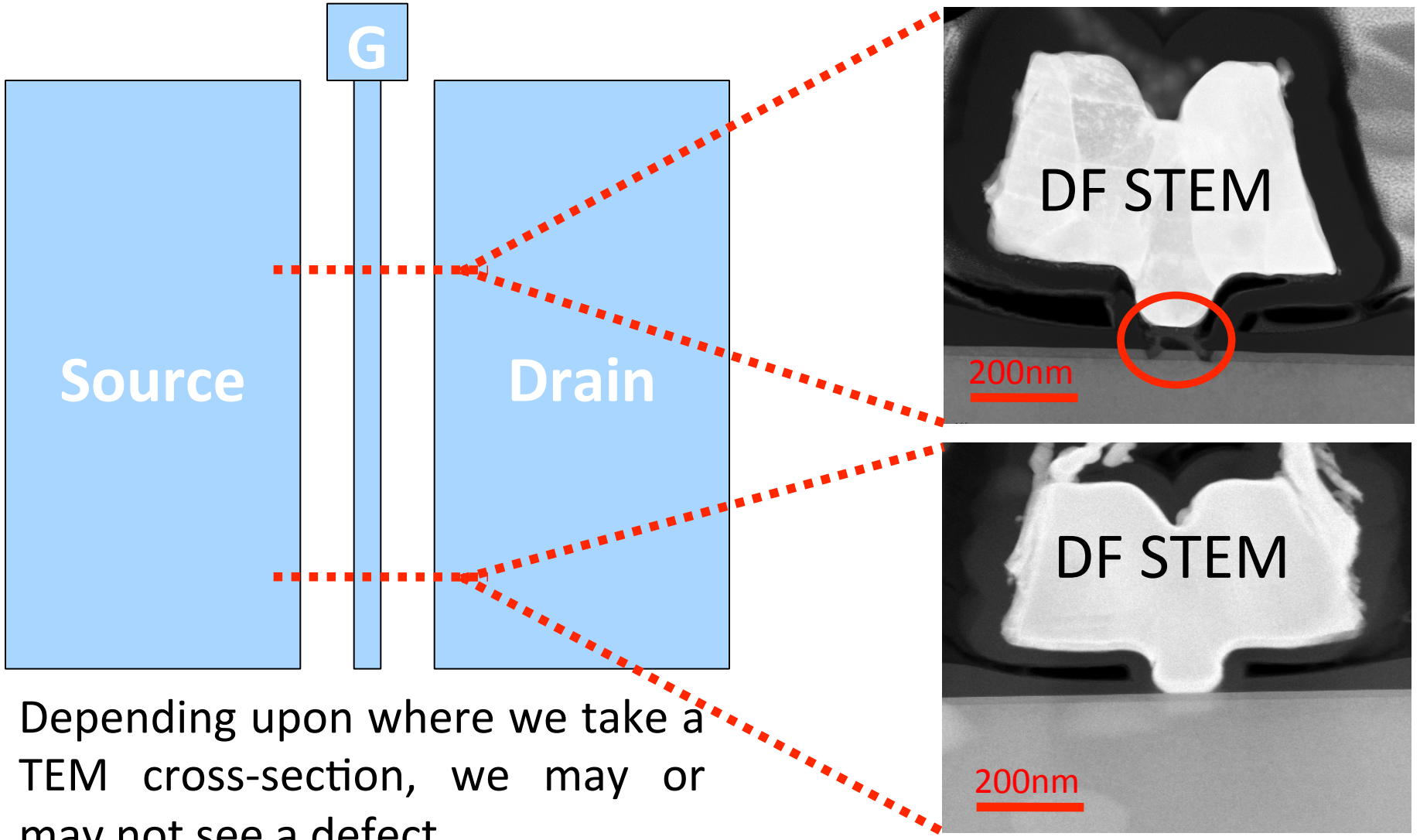
Outline

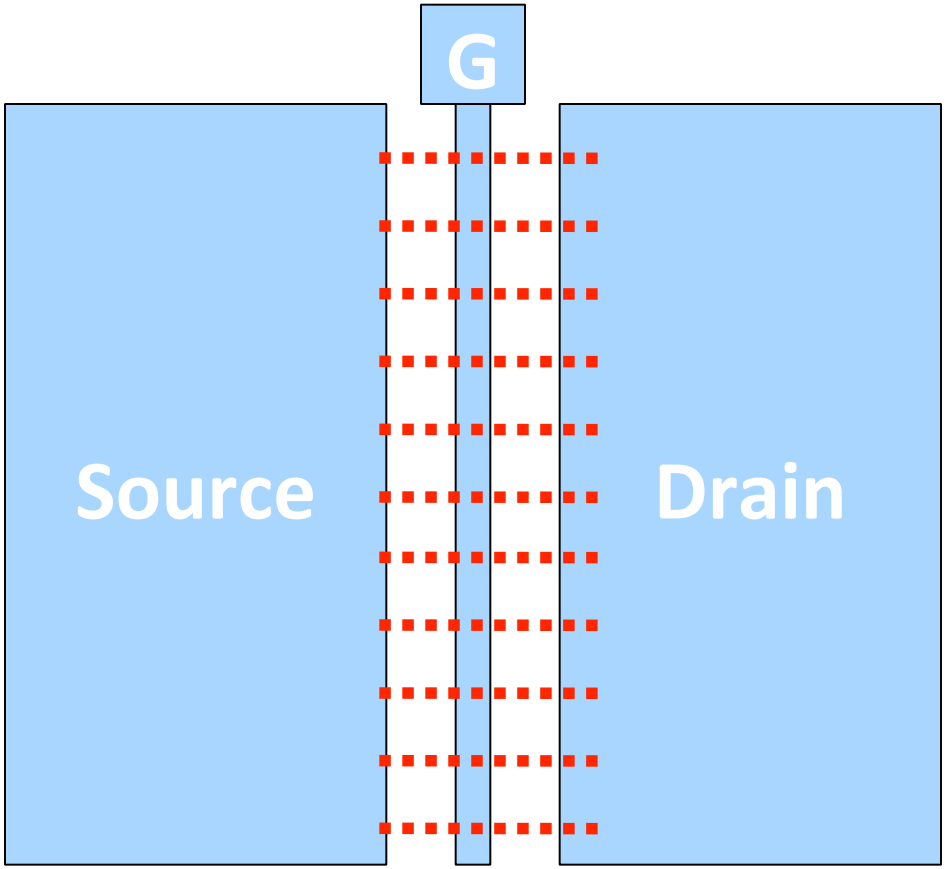
- Motivation
- Deprocessing Method
  - Wet Chemistry and Selectivity
- Under-Gate Defects
  - Defect Density and Gate Leakage
- Crack-Like Defects
  - SEM and TEM Analysis
  - CL Analysis
- Future Work

Motivation



Depending upon where we take a TEM cross-section, we may or may not see a defect.

Motivation



150um Gate / 5um per TEM crosssection
= 30 TEM cross-sections

40 TEM cross-sections * 1 hr per section
= 30 hours of FIB time
= $1,050 per device

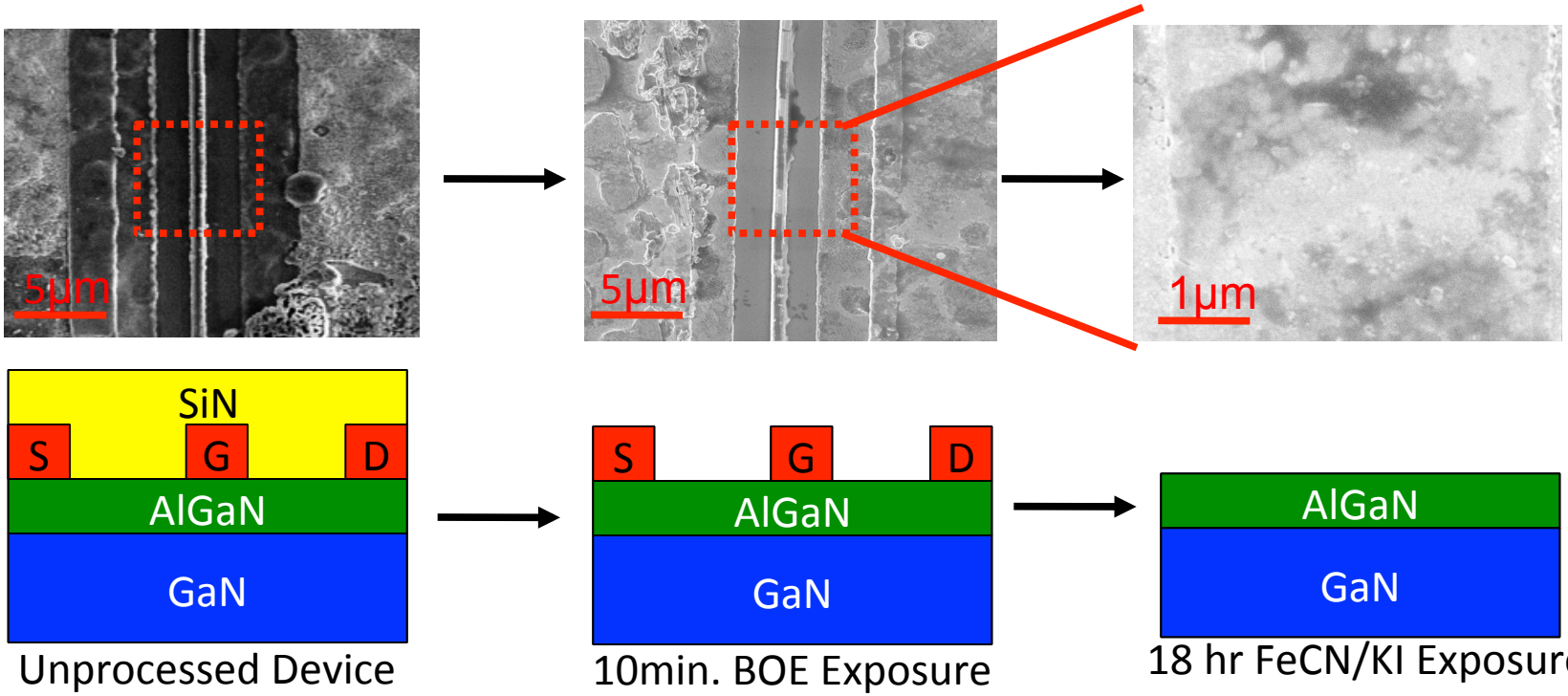
40 TEM cross-sections* .5 hr per section
= 15 hours of TEM time
= $525 per device

= $1575 Total

150um Gate Deprocessing
= 1 day turn-around for wet chemistry
= $75 of SEM Time

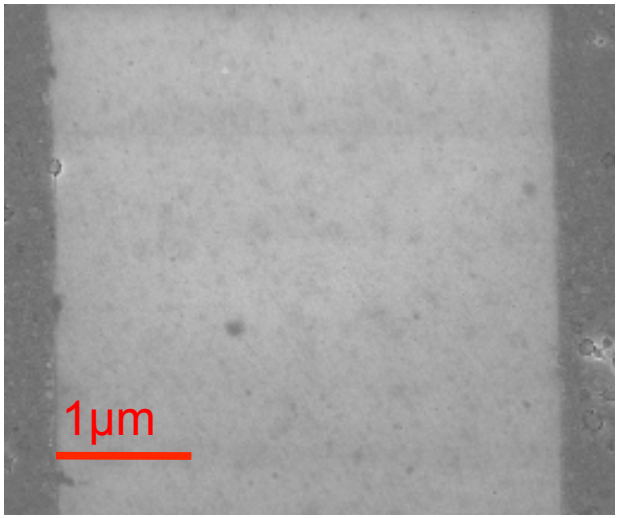
Deprocessing allows us to prepare and evaluate the sample quickly and **inexpensively** in comparison to TEM or slice-and-view SEM.

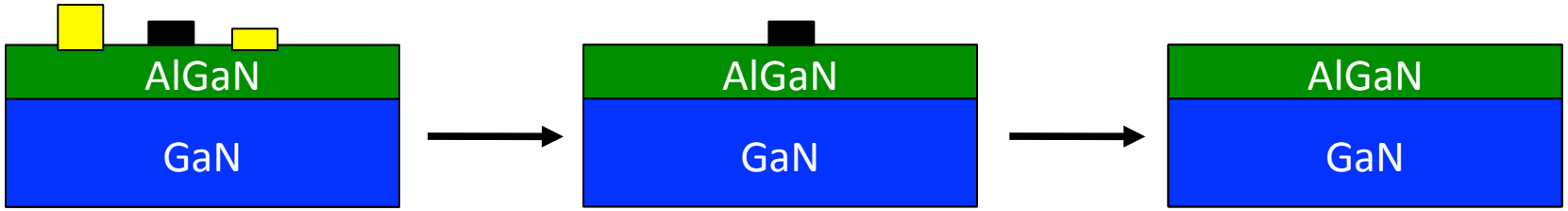
Deprocessing



The SiN and Metal layers can be easily removed using BOE and TFAC Metal Etchant. However, SiN stringers and organic contaminants are still present.

Deprocessing

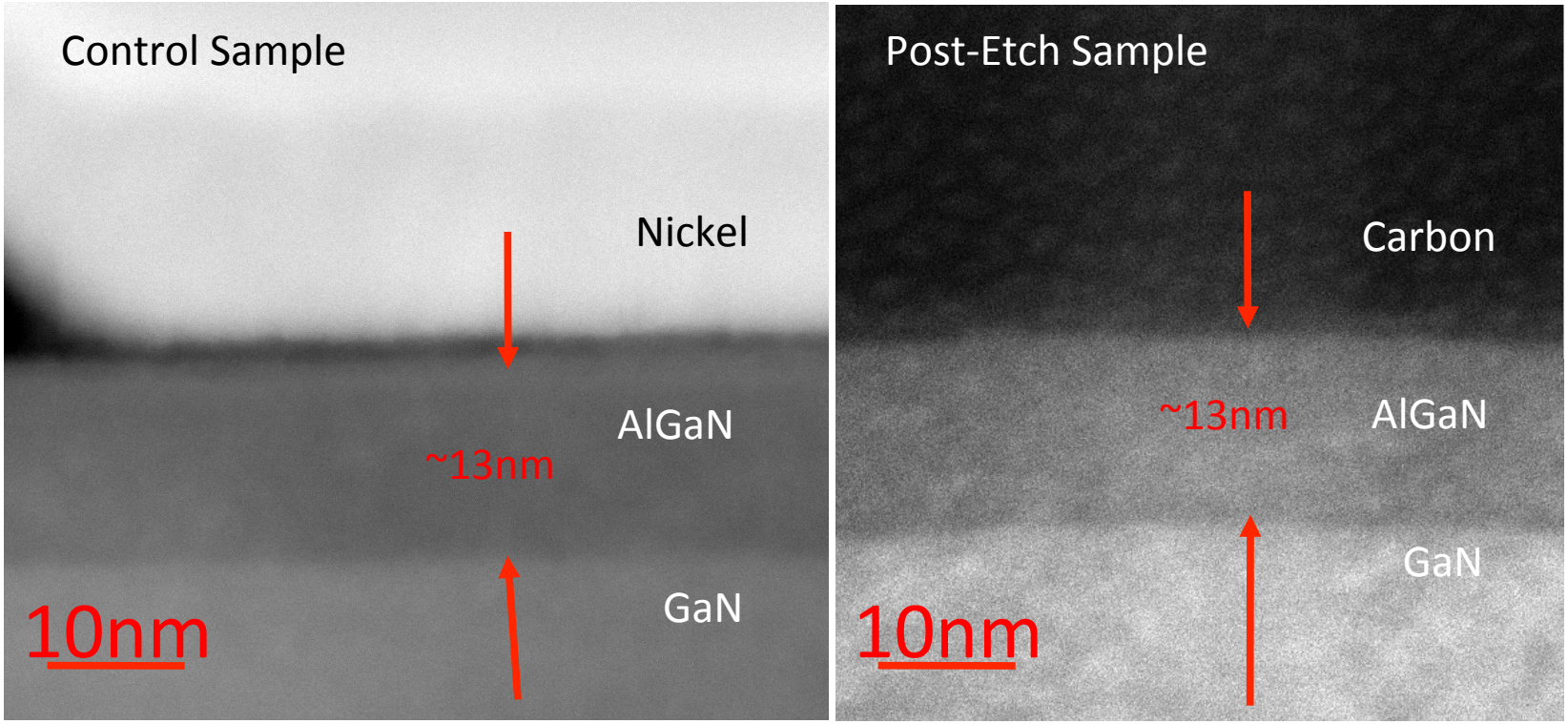




As-Etched Sample | 10 min. BOE Exposure | Ultrasonic Clean

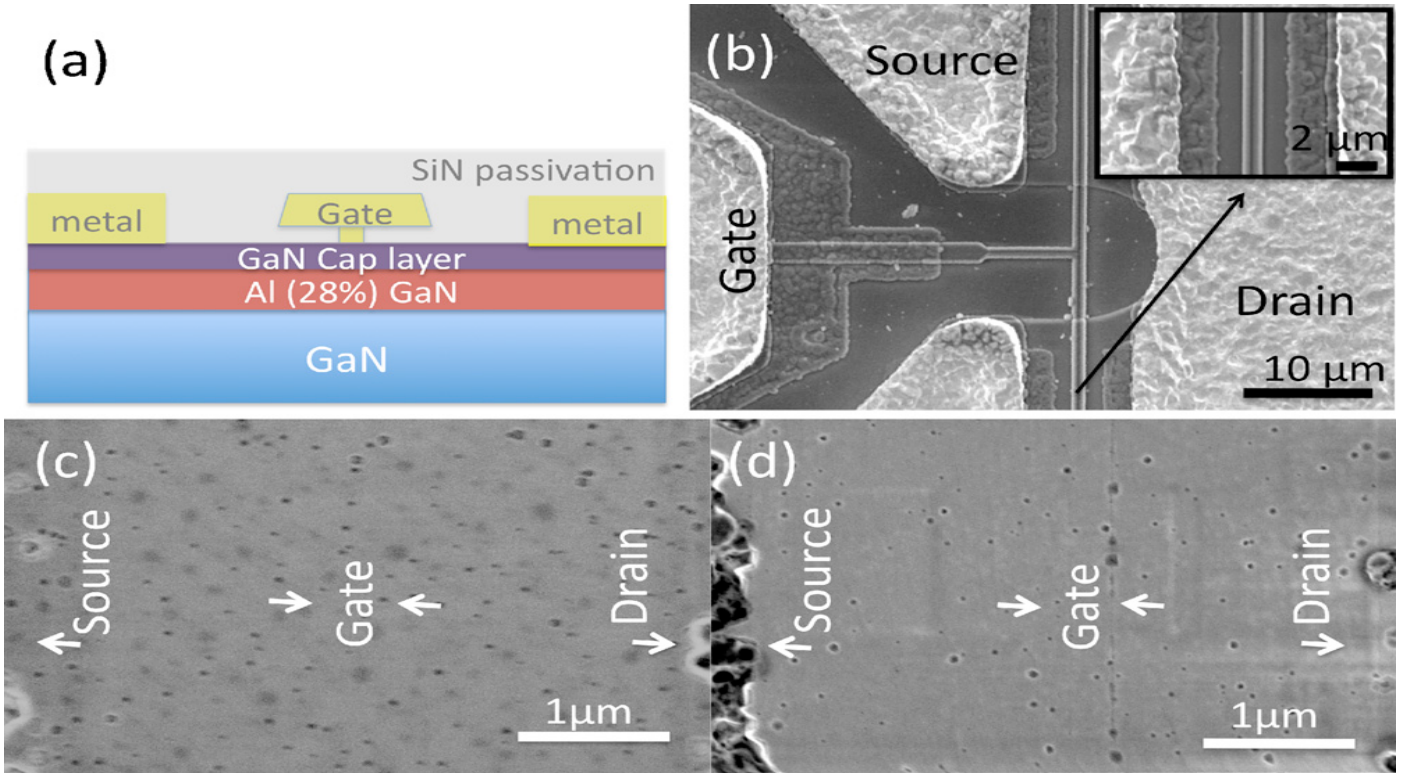
The SiN stringers can be removed with a second BOE exposure while the organic contaminants can be removed with a 10 min. ultrasonic clean in acetone followed by a 10 min. ultrasonic clean in methanol.

Deprocessing



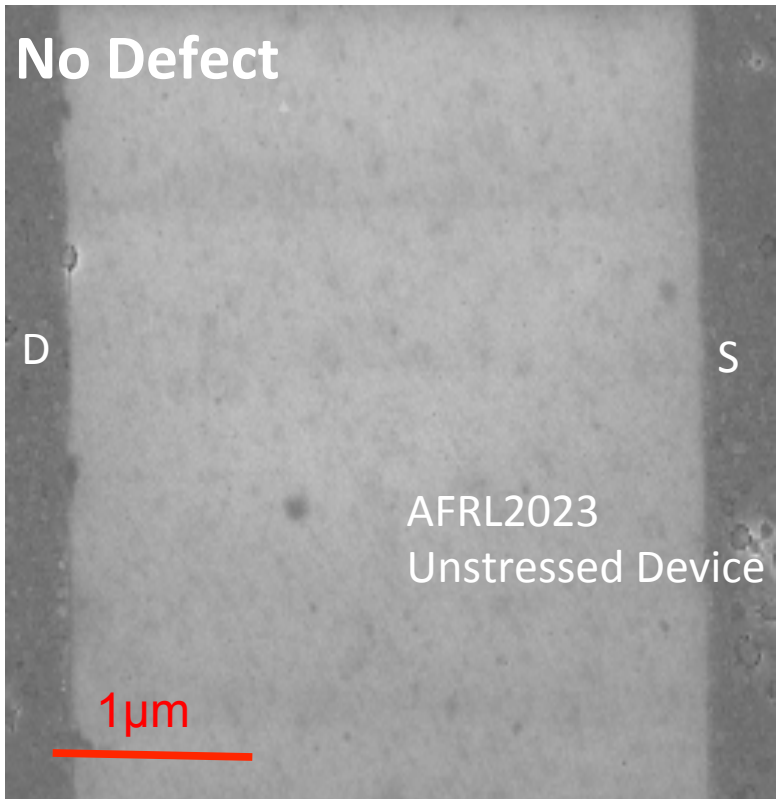
Evaluation of un-etched and etched samples using cross-sectional TEM demonstrates that the etch solutions used do not appear to etch the AlGaN layer. **Deprocessing is perfectly selective.**

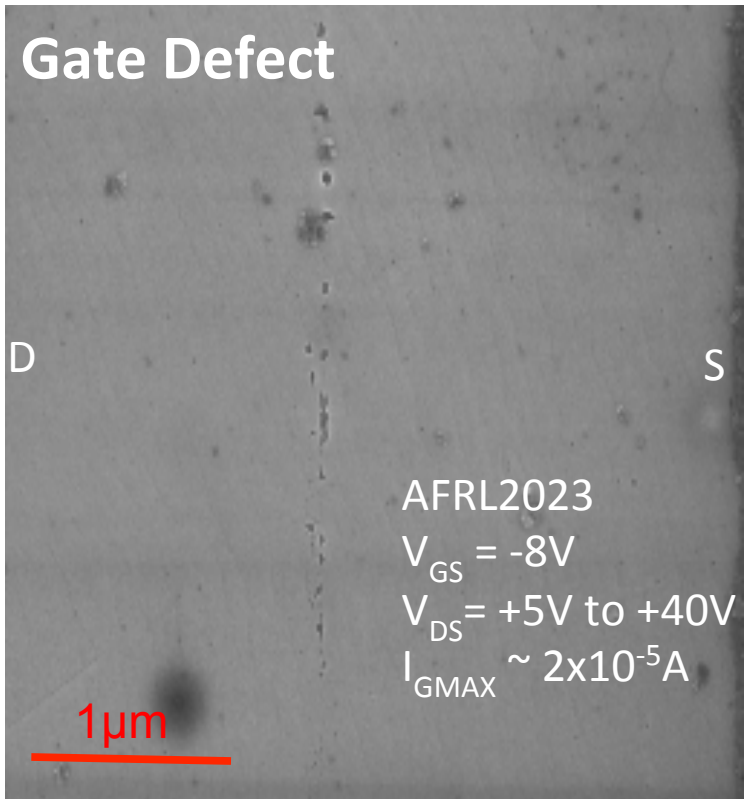
Under-Gate Defects



Defects under the gate contact were first evaluated using deprocessing by MIT*. **They used an Aqua Regia solution, which resulted in severe pitting of the surface**, likely due to reactions with threading dislocations. (* Makaram et al., APL **96**, 233509)

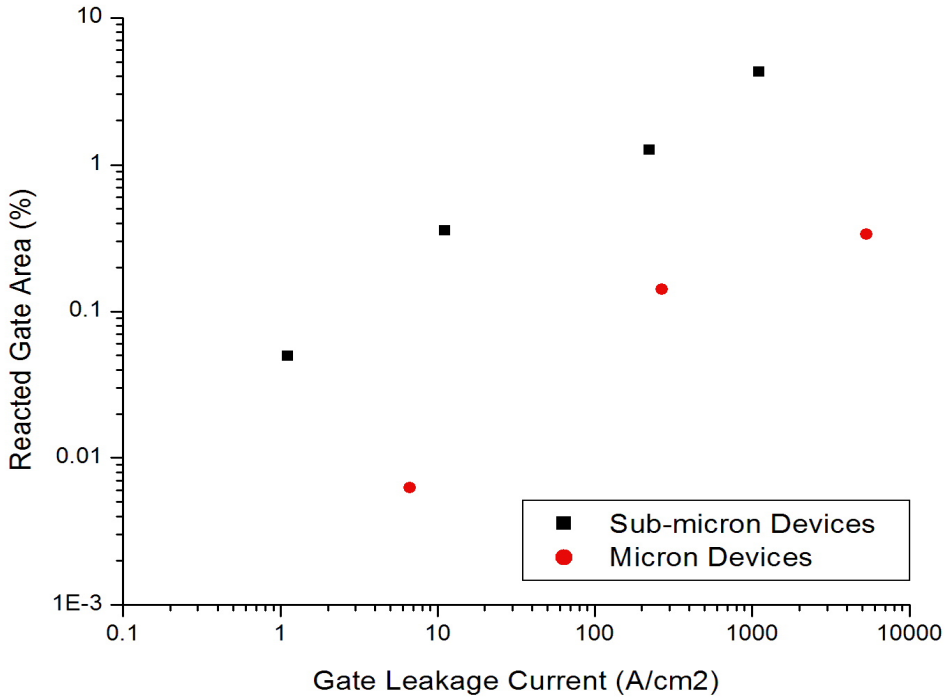
Under-Gate Defects





The use of FeCN/KI solutions allows us to eliminate the pitting reactions. **This is the first observation of gate-consumption related defects in a Ni-gate HEMT using deprocessing.**

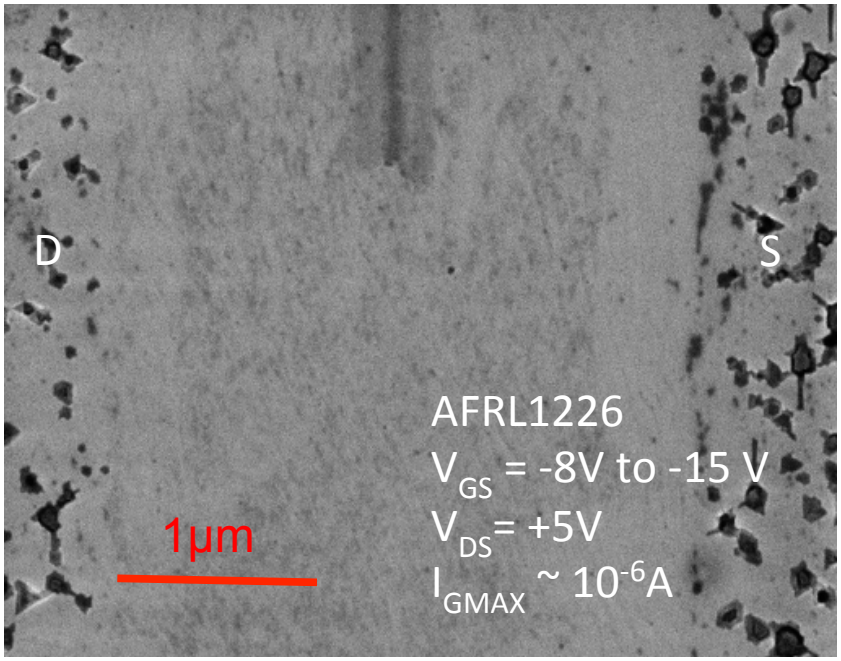
Under-Gate Defect

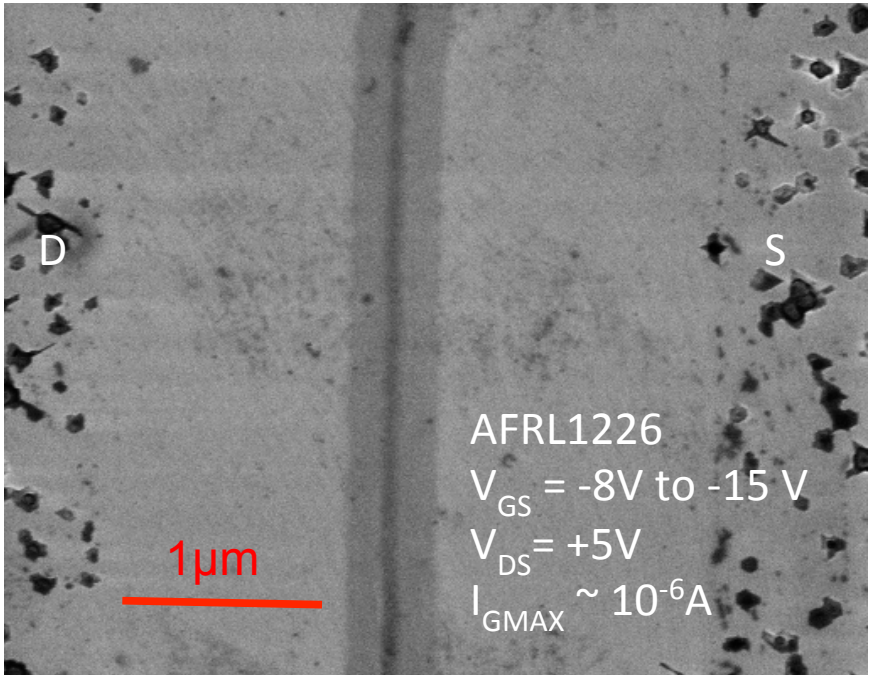


AFRL 1314, 2022, 2023, 2024
V_{GS} = -8V
V_{DS} = +5V to +60V

The consumption-related gate defect appears to have some relation to the gate current density. **High gate current densities correspond to large consumption defect densities.**

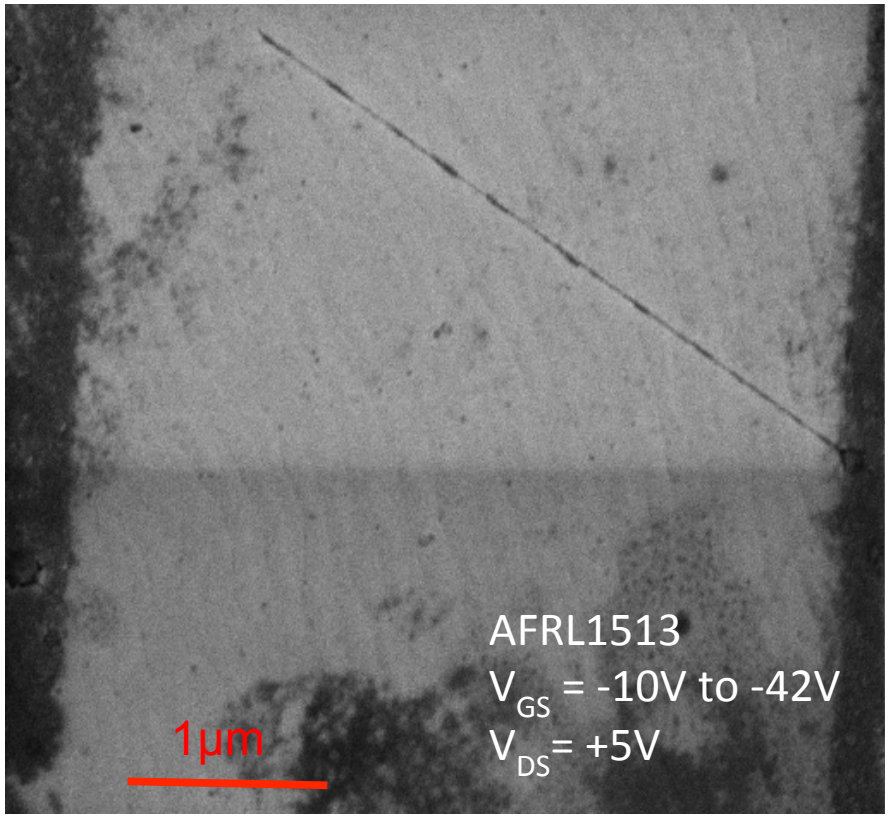
Under-Gate Defects

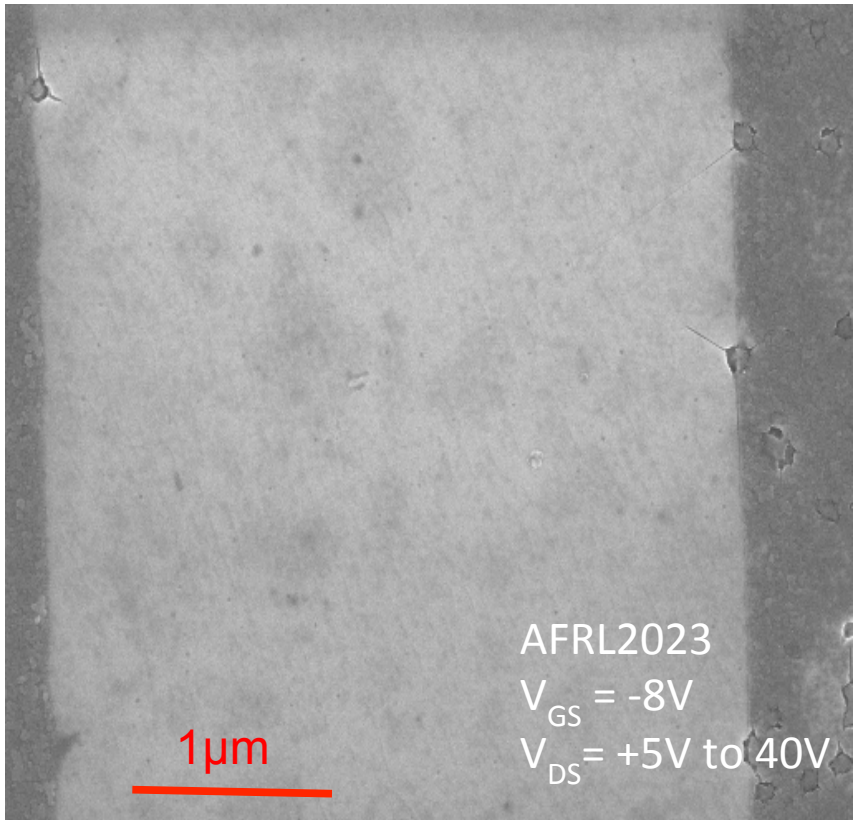




We have also observed a new type of defect not yet reported in the literature. This defect doesn't appear to be consumption related and it occurred on a device that was stressed below V_{CRIT}.

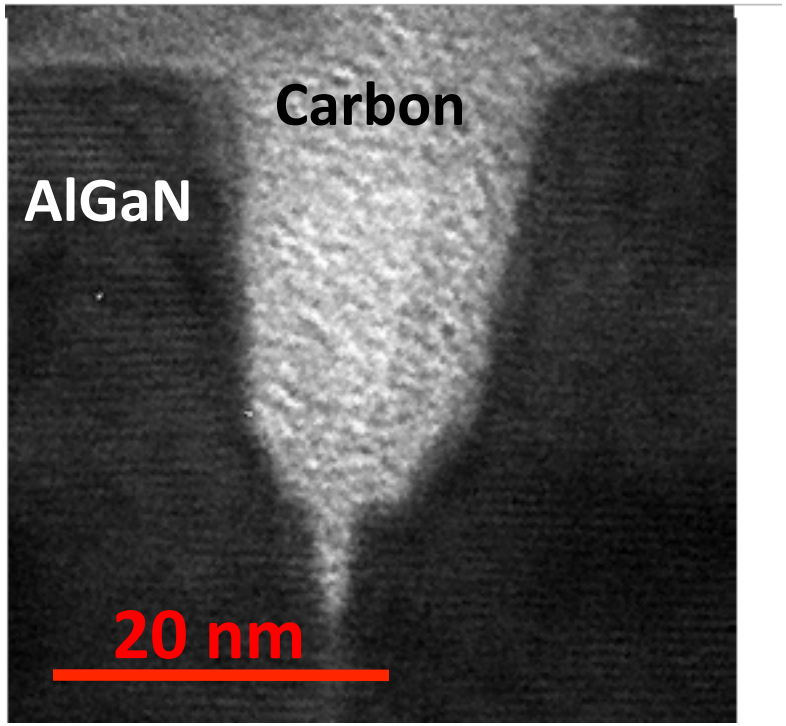
Crack-Like Defects

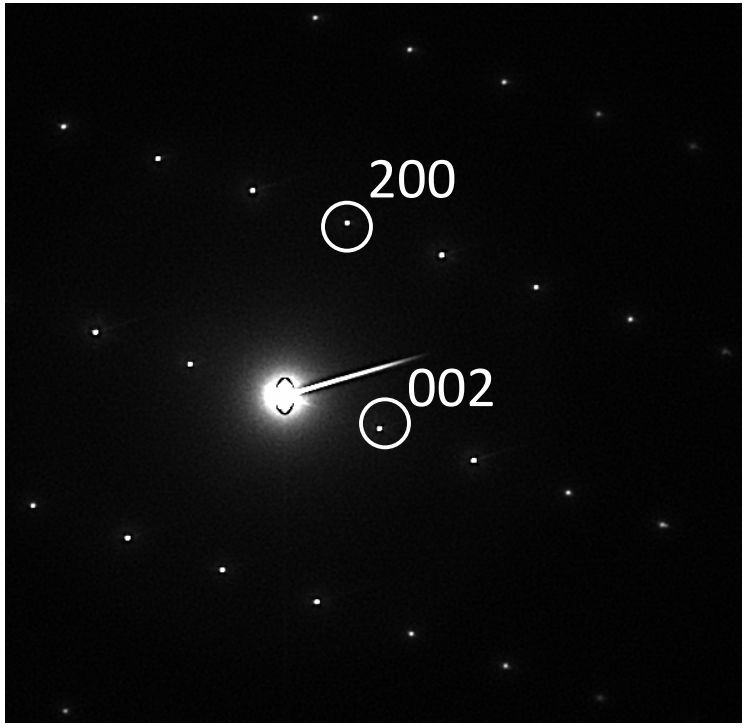




We have also observed crack-like defects in the channel of the HEMT devices. The cracks appear to be confined to the AlGaN and they also appear to radiate from the ohmic contacts.

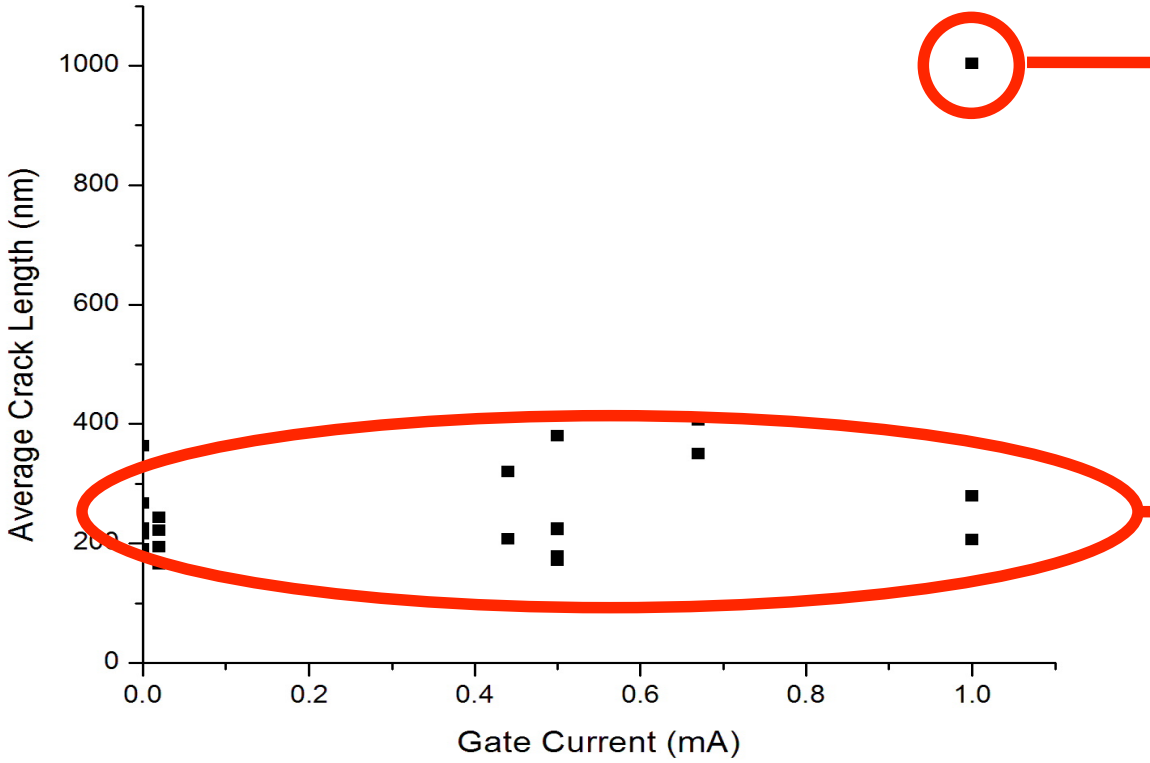
Crack-Like Defects





The crack-like defects present in the channel appear to be confined to the AlGaN. **They are roughly 30nm deep and are oriented along the {10$\bar{1}$0} directions rather than the prism directions.**

Crack-Like Defects

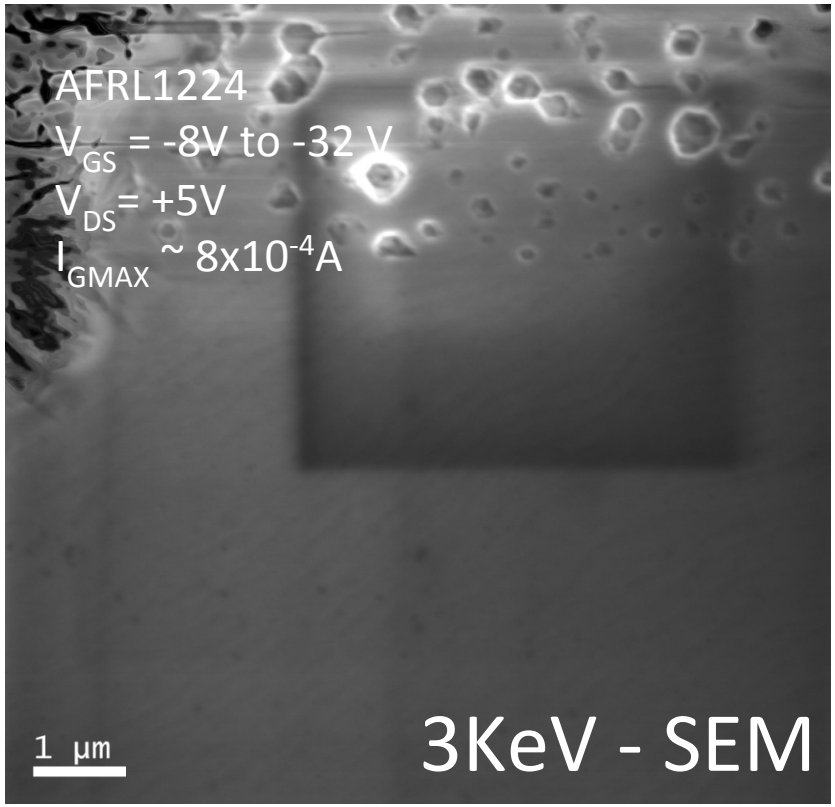


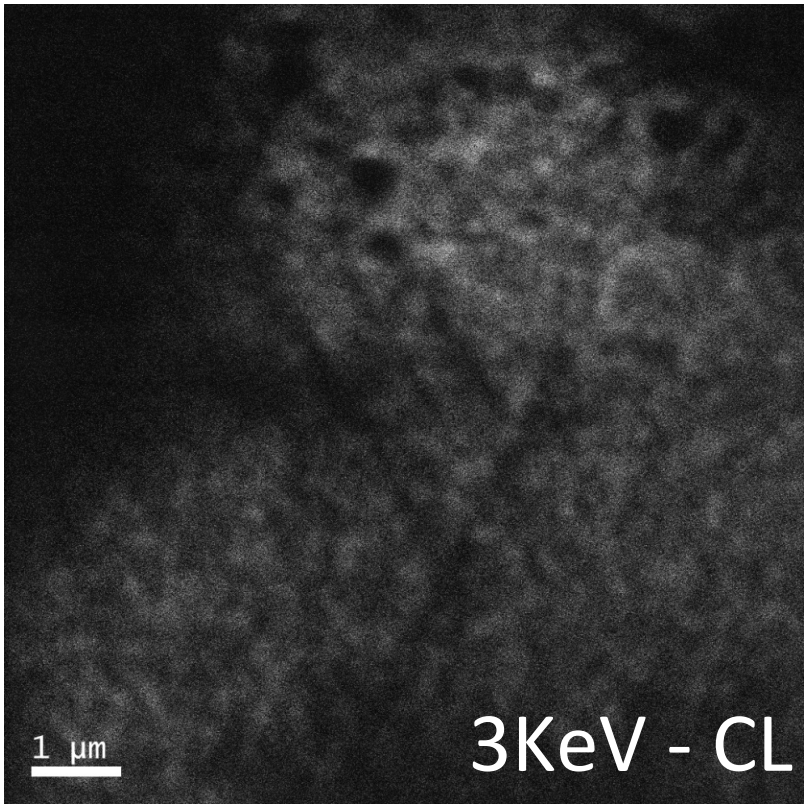
AFRL1513
V_{GS} = -10V to -42V
V_{DS}= +5V

AFRL 1314, 2022, 2023, 2024
V_{GS} = -8V
V_{DS} = +5V to +60V

The crack-like defects are present prior to stressing. Stressing may induce crack growth (likely during on-state), but crack likely formation occurs during processing.

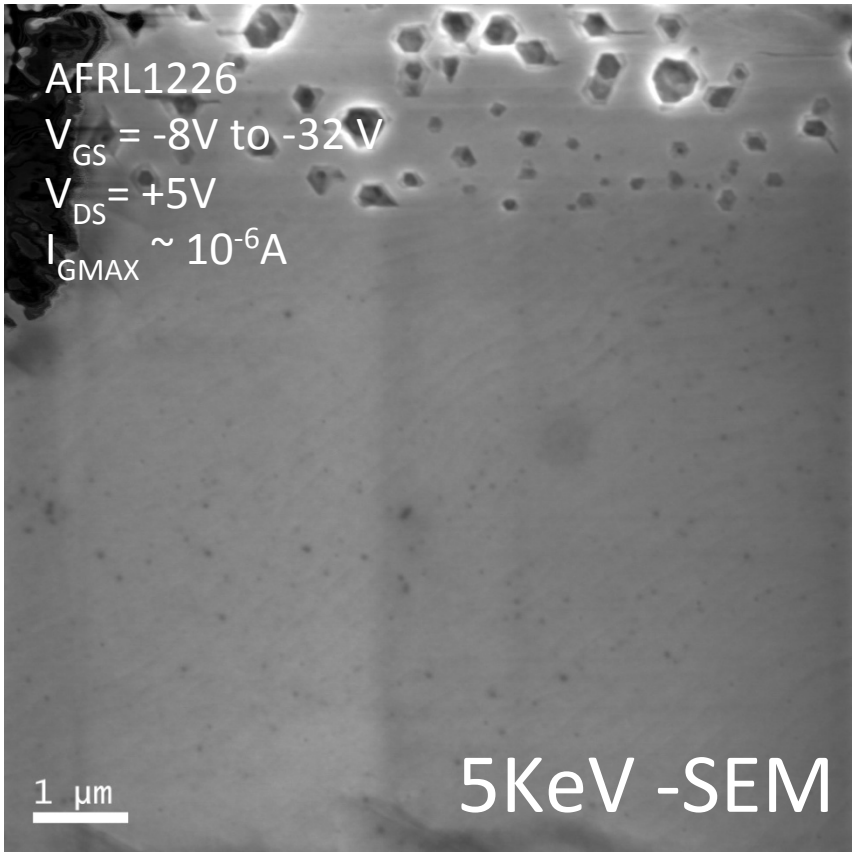
Crack-Like Defects

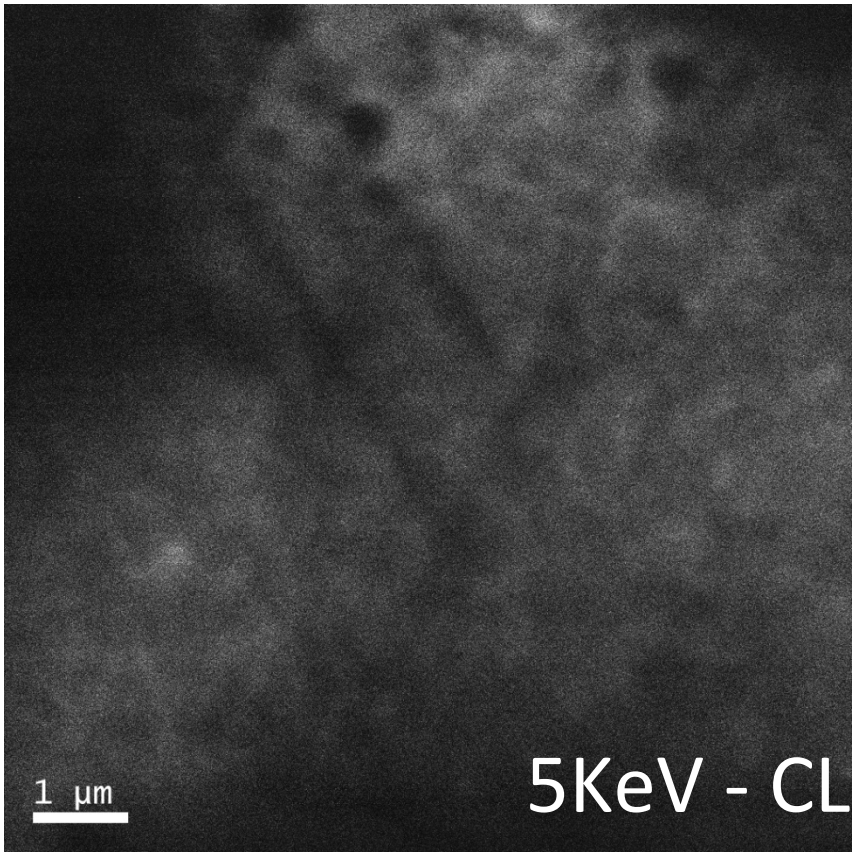




Recent studies with CL have revealed that trap formation appears to be occurring prior to crack propagation. Defects are more visible at low e^- energies, so they're confined to the surface.

Crack-Like Defects



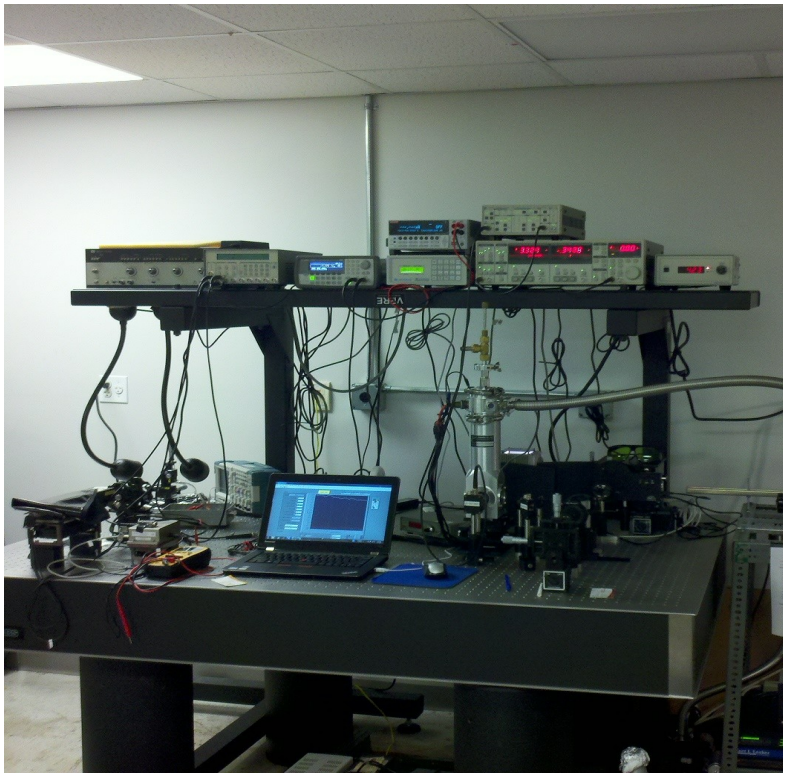


Recent studies with CL have revealed that trap formation appears to be occurring prior to crack propagation. Defects are more visible at low e^- energies, so they're confined to the surface.

Conclusions

- The deprocessing method described before has been refined to improve surface quality.
- A defect related to consumption of the AlGaN by the Ni-gate has been observed with SEM.
  - Gate leakage appears to increase with increasing consumption.
- A crack-like defect radiating from the ohmic contacts has been observed on both the source and drain sides using SEM/CL.

Future Work: Test System



Janis VPF Series Cryostat

Keithley 2401 Sourcemeter

Lakeshore Controller

- Temp. Range: 77K – 600K
- Probes: Tungsten (5)
- Max Current: 1A
- Max Voltage: 20V
- Vacuum: Turbopump
- User Input: Labview

Future Work: Crack Defect

- Does TEC mismatch between the metal and semiconductor cause cracking?
- I_G vs. V_G and I_{DS} vs. V_{DS}/V_{GS} characterization of all devices both pre-stress and post-stress
- Thermal Annealing Experiment
  - 300°C to 800°C followed by deprocessing
- Joule Heating Experiment?
  - I_{DS} vs. V_{DS} with V_G=0 followed by deprocessing

Future Work: Gate Defect

- How do current versus inverse piezoelectric strain influence breakdown?
- I_G vs. V_G and I_{DS} vs. V_{DS}/V_{GS} characterization of all devices both pre-stress and post-stress
- Forward Biasing Experiment (Current)
  - Time Dependance: Reaction Mechanism
  - Current/Temperature: Reaction Energetics
- Reverse Biasing Experiment (Field)
  - Time Dependance: Reaction Mechanism
  - Current/Temperature: Reaction Energetics